A COMPARISON OF MOUNTAIN SLOPE AND RADIOSONDE OBSERVATIONS

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ABSTRACT

A series of observations made on the slope of Pikes Peak (Colorado) during a survey trip were compared with data from the nearest radiosonde station at Denver. The slope measurements gave a good indication of free-air conditions, as determined by the radiosonde. A further consideration of mountain slope observation chains as a supplement to regular upper-air soundings is suggested.

1. INTRODUCTION

On May 2, 1963, a brief survey of the upper part of Pikes Peak was made for the purpose of selecting a site for radio propagation experiments.[1] Tests were made on the performance of two microbarographs at high altitude, and a number of psychrometric observations were made on ascent and descent with a battery-powered psychrometer. These slope observations were found to be in relatively good agreement with the "free-air" values measured by the Weather Bureau radiosonde station in Denver, about 65 mi. north of the peak.

Later in the year hourly surface observations were made on the summit, and these also gave useful indications of the free-air properties as observed at Denver.

Although somewhat neglected in recent years, Pikes Peak has a long history of high-altitude meteorological measurements. In October 1873 the U.S. Army Signal Service established a station at the summit which was the highest meteorological observatory in the world (14,110 ft. above sea level and 8,000 ft. above the nearby plains). Observations were made continuously from November 1874 to September 1888, after which the Weather Bureau operated the station for about two years from 1892 to 1894. In 1874 Lt. H. H. C. Dunwoody made comparative measurements of temperature at the base and summit of Pikes Peak in one of the earliest attempts to determine the change of temperature with altitude [13, 10].

C. F. Marvin made a large series of psychrometric observations in Colorado Springs and at different elevations on Pikes Peak in 1885, and also made similar observations in Washington with H. A. Hazen. These data were used by Prof. Wm. Ferrel in determining the constants in the psychrometric formula, and Marvin later published tables for dew point and relative humidity based upon this formula [12, 6].

2. OBSERVATIONS

On the ascent of the peak, on May 2, 1963, measurements were made while holding the psychrometer at arm's length out of the window of an automobile moving at about 25 m.p.h. up the road to the summit. As soon as maximum depression of the wet bulb occurred, the elevation was observed on an aircraft altimeter. On the descent, a stop was made at about each 1000-ft. change in elevation and the psychrometer was operated at eye-level several yards away from the vehicle.

The observations were started in Colorado Springs at 6,000 ft. at 1010 MST, the summit was reached at 1120 MST, and the descent was made between 1322 and 1545 MST. Sunrise at the base of the peak was at about 0500 MST on May 2, and skies were nearly clear in the early morning. By 0900 MST some cumulus clouds were forming, and the 1000 MST observation at the airport east of Colorado Springs remarked on "Towering cumulus west, north, and east. Virga northwest through northeast." Cloudiness was increasing rapidly during the ascent, and there were occasionally some snow pellets falling on the summit during the interval between ascent and descent. Winds on the summit were west to northwest at about 15–20 m.p.h. There were clouds observed below the summit at some distance from the peak, with many patches of virga in the vicinity and a few showers probably reaching the ground, but the summit was at no time obscured by clouds. Snow pack on the peak was much below normal for the time of year, and ground conditions could best be described as "dry". Winds at 500 mb. (18,700 ft.) were westerly at about 40 kt. at the time of the surface observations on the Peak.

An attempt was made to obtain additional slope data in August, but observations had to be discontinued because of heavy rain and hail. However, during radio experiments in July and August 1963 there were hourly surface observations at the Pikes Peak summit transmitter site, and four radiosonde flights were made daily at Denver.[2]

3. DISCUSSION

Humidity was calculated from the wet and dry bulb readings by using Ferrel's formula and assuming the

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[2] RAOBs by U.S. Weather Bureau.

standard atmosphere pressures for the various elevations [5] since no absolute pressure values were obtained. The data for the ascent and descent on May 2 are shown in figure 1. The higher temperatures observed over much of the ascent (compared with the descent) may have been a result of the method of observation, but are more probably the result of early morning heating of the slope under nearly clear skies. As cloudiness increased and reduced the incoming radiation, this excess of heat was lost to the air, and wind-induced mixing resulted in a closer approach to free-air temperatures on the descent. Relative humidity did not vary greatly during the day except near the summit of the peak, but below about 8,500 ft. the dew point was 5° to 7° F. lower in the afternoon. The average lapse rate for the 8,000-ft. interval between Colorado Springs and the summit was 5.8° F. on ascent and 5.4° F. on the descent. Over the same interval (6,000–14,000 ft.) the 1700 MST RAOB at Denver had an average lapse rate of 5.5° F. per 1000 ft.

The RAOB data from Denver are compared with the Pikes Peak surface data in figure 2. Although the slope values at this time of day were generally higher than the free-air values at the same altitude, they give a useful approximation of the characteristics of the air mass. The 500-mb chart for 1700 MST on May 2 (fig. 3) indicated that the air mass in the Pikes Peak area was probably about 1° C. warmer than above Denver at 18,700 ft., and a similar trend might be expected at lower levels. However a large part of the temperature difference was probably a result of surface heating effects in the air near the slope.

The summit observations in July and August 1963 which corresponded with RAOB release times (0500, 1100, 1700, 2300 MST) were compared with the data at the RAOB pressure level corresponding to the station pressure at the summit (fig. 4). The averages of the 6-hr. observations for a 4½-day period in each month were as follows:

	Temperature (°C.)		*Relative Humidity (percent)*	
	July	August	July	August
Pikes Peak	7.33	3.44	61.3	76.5
Denver RAOB	7.04	3.22	53.2	63.2

The difference between the summit and free-air observations varied considerably with time of day. The mean differences in 35 observations were: temperature 1.4° C.; relative humidity 13 percent. The temperature difference was greatest at 1100 MST (2.0° C.) and least at 2300 MST (1.1° C.); the difference in relative humidity was greatest at 1700 MST (22 percent) and least at 2300 MST (9 percent). The temperature at Pikes Peak was always higher than the 14,000 ft. temperature over Denver at 1100 MST, and always lower at 2300 MST (except on one night with fog on the summit). The relative humidity was nearly always higher on the Peak than in the free air over Denver, regardless of the time of day.

Many of the larger differences in temperature or humidity observed during the 10-day period appear to be the result of non-uniform distribution of shower activity and cloudiness. When similar conditions prevailed at Denver and the Peak, there was good agreement between the summit and radiosonde indications of the magnitude and direction of temperature and humidity changes in the free air. The data suggest that corrections might be worked out to provide still better estimates of the free-air conditions from the slope observations.

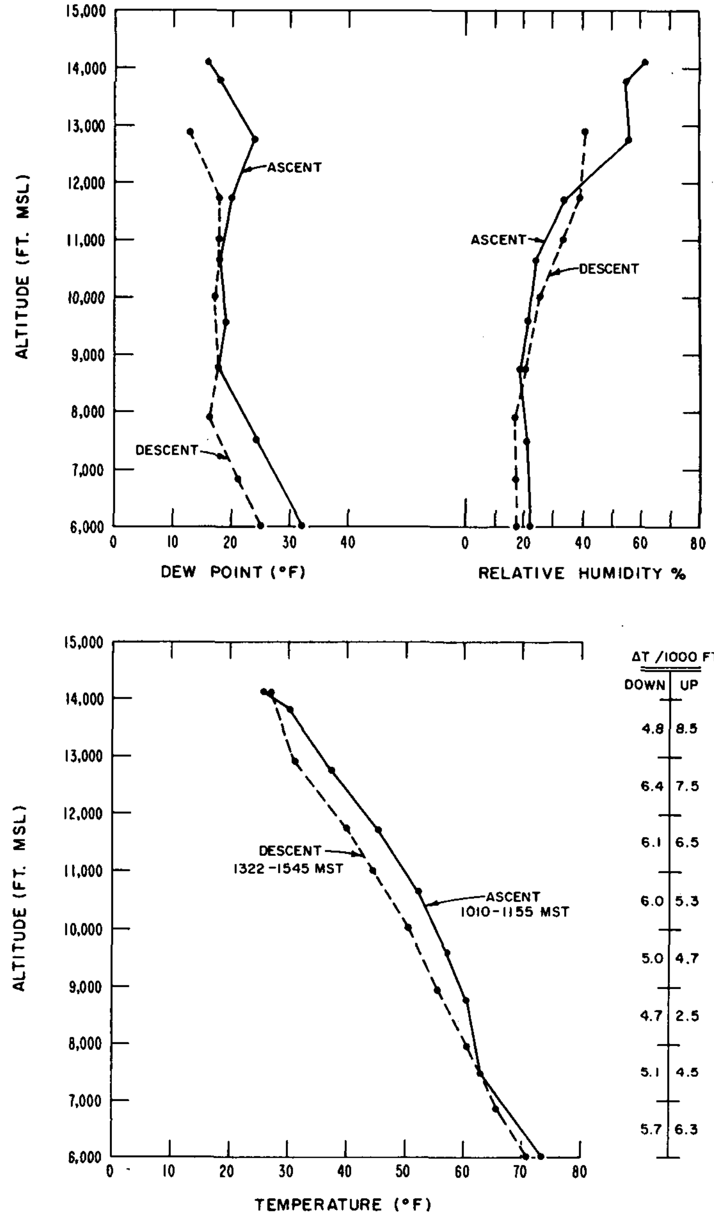

FIGURE 1.—Observed temperature and humidity on slopes of Pikes Peak, May 2, 1963.

4. OTHER SLOPE—FREE-AIR DATA

Investigations of the slope—free-air relationship in Europe were reported by von Hann [15], von Ficker [14], and R. Süring [11]. While the mountains were generally found to be colder than the free air (on the average), there

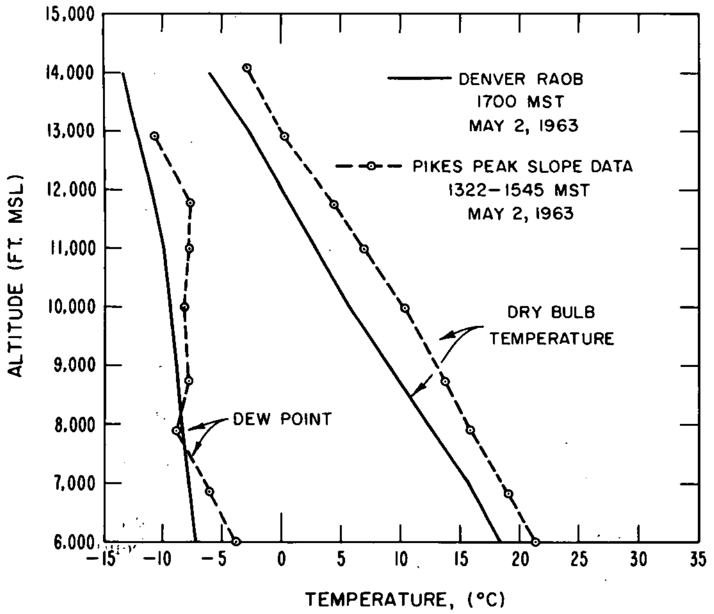

FIGURE 2.—Comparison of slope and RAOB data.

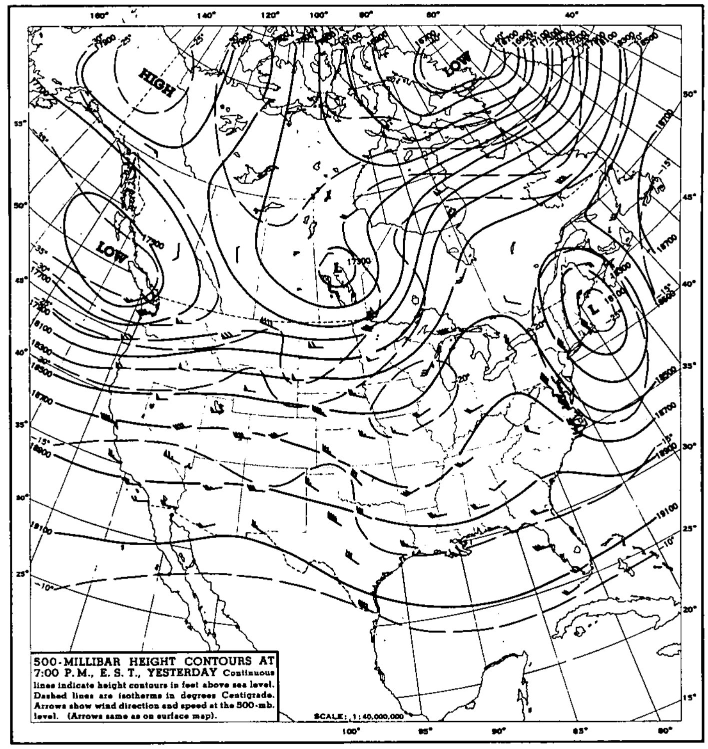

FIGURE 3.—500-mb. chart for 1700 MST, May 2, 1963.

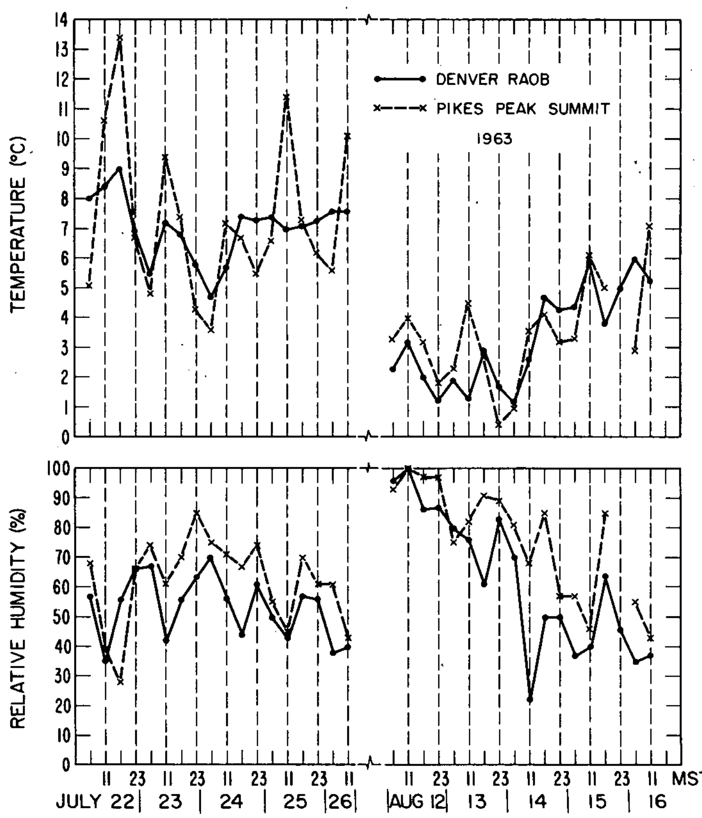

FIGURE 4.—Comparison of summit and RAOB data.

were indications of considerable diurnal, seasonal, and wind-related variations. Von Ficker noted that in winter the Zugspitze (2,964 m.) averaged 1.8° C. colder than the free air at 7 a.m. but at 2 p.m. the peak was only 0.4° C. colder; in summer the peak was 1.1° C. colder at 7 a.m. but was 1.3° C. warmer than the free air at 2 p.m.

Fergusson [3] found from kite and airplane observations at Mt. Washington, N.H., that the lapse rate within 10 to 20 m. of the slope was very large, and that there was a marked influence from wind: at midday with moderate to high winds the summit temperature was generally lower than the free air, but with light winds the summit was warmer than the free air. He estimated that instruments exposed on a 50-m. tower would be above some of the larger effects of the mountain.

Schell [8, 9] compared aircraft data with observations on Mt. Washington and Mt. Lafayette, and found a greater lapse in the free air than along the slopes, also a considerable variation with elevation and time of day. From a consideration of air mass type, lapse rate, wind, and season, he found that the mountain observations could be used to estimate the free-air temperature to within 0.5° to 1.5° C.

More recently Hänsel [4] compared a 5-yr. series of observations on Brocken Mountain (1,134 m.) with free-air data from the nearby Wernegerode radiosonde station. He found that the mean temperature on the mountain was lower than the free-air value throughout the year, but the average 1200 GMT temperature was higher on the peak than in the free air from March through September (by about 1° C. in June). At 0000 GMT the peak was colder throughout the year (by about 1.4° to 2.2° C.). Hänsel also found that the average relative humidity on the peak was higher than in the free air in all months, and that both temperature and humidity differences were affected by the direction and speed of the wind.

5. CONCLUSIONS

It seems to be fairly well established that *mean* temperatures on high mountains tend to be lower than free-air temperatures at the same level, but diurnal and seasonal departures from the mean are fairly large. The mountain—free-air relationship is affected by air mass differences, winds, cloudiness, precipitation, and surface radiation characteristics (snow cover, vegetation, slope orientation, etc.), but it is possible to obtain useful indications of free-air characteristics from mountain slope observations.

Many phases of meteorological and ecological research would benefit from regular weather observations on selected mountain slopes. In addition, these observations might provide a useful supplement to radiosonde observations, especially in cases of upslope flow. For example, in Colorado there are only two Weather Bureau RAOB stations (Denver and Grand Junction) which report at 12-hr. intervals. Since appreciable changes may sometimes occur in 12 hr., it would be desirable for forecasters to have more frequent data on the lower atmosphere if the data could be obtained quickly and at reasonable expense.

The initial cost of a mountain slope chain of temperature, humidity, and pressure sensing units should not be prohibitive, and the cost of operating such a network (per observation) should be nominal compared to the cost of a radiosonde observation. Data transmission could be by telephone line to the nearest weather station, and the observational sequence could be arranged by a dial code, as is done at some river-stage reporting points. Although difficulties were experienced in the past in maintaining lines on the upper part of Pikes Peak because of high winds, snow, and icing, advances in materials and techniques in recent years should make slope transmission lines more dependable now than in years past. It might, however, be cheaper to use small, battery-powered radio transmitters at each observation point than to construct a telephone line over several miles of mountainous terrain.

It has been suggested by Ekhart [2] that a large mountain system forms its own "atmosphere", extending some distance above and around the system and separated from the free air by discontinuities. This implies that a relatively isolated high peak would be most suitable for slope observations if free-air indications are desired. Pikes Peak is ideally situated in this respect, since it is bordered by the high plains to the east and the main mountain ranges are approximately 60 mi. distant to the southwest through northwest. Additional data for a system design study for Pikes Peak might be obtained at relatively low cost by installing recording equipment on the cog-railway cars, as has been done in Europe [1]. However a truck-mounted mobile observatory of the type described by Schaeffer [7] would be preferable.

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